UV-C Irradiation Reduces Gray Mold Decay and Enhances the Accumulation of Scoparone in Some Citrus Species

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Abstract We examined the effect of UV-C irradiation on the reduction of decay caused by gray mold (Botrytis cinerea Persoon), as well as on the accumulation of scoparone, an important defensive secondary metabolite, in the flavedo (exocarp) of four different Citrus species. Fruits were inoculated with gray mold 4 days after UV-C irradiation. In irradiated Satsuma mandarin and Hyuganatsu fruits let to a delay of disease incidence, and the reduction of the decay radius in Satsuma mandarin, ‘Kiyomi’ tangor, and Hyuganatsu fruits. In contrast, control fruits of Satsuma mandarin, ‘Kiyomi’ tangor, and Hyuganatsu, which had been inoculated with gray mold but had not been subjected to irradiation, showed a pronounced fungal penetration at 7 days post-inoculation. The amount of scoparone accumulation in the inoculated flavedo varied among species and with the irradiation treatment. Scoparone accumulated more rapidly and reached higher levels in irradiated ‘Kiyomi’ tangor and Hyuganatsu than in the control fruits. Interestingly, the disease incidence in the irradiated ‘Eureka’ lemon fruits was considerably lower than that in the other species. However the average radius of decay in the lemon fruits showed no decease and the levels of scoparone were far lower in both irradiated and non-irradiated fruits. We concluded that UV-C irradiation enhanced the accumulation of scoparone and increased resistance to gray mold in the other three Citrus species. These findings contribute to the decrease of the postharvest disease caused by the fungus in some Citrus species.

Key words: Botrytis cinerea, Citrus, Decay, Phytoalexin, Scoparone, Ultraviolet-C

Introduction

Citrus fruits grow throughout the world under tropical and subtropical climate conditions with suitable soil, sufficient moisture, and low incidence of frost (Burke, 1967). In the citrus-producing countries, considerable losses of fruits result from inadequate storage facilities and improper transport. Estimated average losses in these countries are amount to 28% of the total crop (Ladaniya, 2008). Such losses are mainly due to pathogenic fungi, which primarily infect the host through wounds inflicted during harvesting, handling, and processing of the fruits. Fungi from several genera, including Botrytis, Penicillium, Alternaria, Colletotrichum, and Fusarium, cause postharvest decay in agricultural produce (Droby and Lichter, 2007).

Botrytis cinerea Persoon is a necrotrophic pathogen with a wide range of hosts, more than 200 plant species (Oliver and Solomon, 2010; Dean et al., 2012), that causes considerable decay in many crops of high economic value. B. cinerea causes botrytis fruit injury disease in growing Citrus plants and gray mold disease in stored fruits, leading to rot of lemons and mandarins as postharvest disease in tropical and subtropical areas (Nitta, 2001; Shigeta, 2001; Naqvi, 2004). Infection and contamination with this disease may occur at different levels of the supply chain, namely in the field, after harvest in the packinghouse, during transport and at the sale (El-Otmani et al., 2011). This mold rot reduces both the quantity and quality of Citrus fruits.

In plants, the primary line of resistance to B. cinerea is the cuticular membrane. The cell wall defenses are triggered by recognition of pathogen-derived molecules, including pathogen-associated molecular patterns (PAMPs), using membrane-localized pattern recognition receptors. The recognition of pathogens is linked to the accumulation of secondary metabolites, including phytoalexins, in various plant species (Mengiste et al., 2009). Phytoalexins are low-molecular-weight secondary metabolites that are formed de novo by plants as a result of physical, chemical, or biological stress. These compounds confer resistance to fungal or bacterial diseases. The accumulation of phytoalexins depends on the plant genotype or on the genotypes of both the plant and the pathogen (Parkayastha, 1994).

Some coumarins, which are constitutive and induced, have been identified in the reproductive organs of fruits in Citrus such as scoparone (6,7-
dimethoxy coumarin) (Adek and Sztejnberg, 1994). The compound is a citrus phytoalexin (Adek et al., 1986; Adek and Sztejnberg, 1988) which delays bioactivities in animals, including humans (Hoult and Payá, 1996; Jang et al., 2005; Jang et al., 2006; Sourivong et al., 2007; Choi and Yan, 2009; Atmaca et al., 2011). Iqbal et al. (2013) described the ability of scoparone to interfere with the tumor necrosis factor-α (TNF-α), which is one of the most important regulatory proteins in animal immune systems.

Scoparone was isolated from the bark of Citrus spp. trunks and branches after the plants had been inoculated with the pathogen Phytophthora citrophthora (Adek et al., 1986; Adek and Sztejnberg, 1988). In resistant species of Citrus, the concentration of scoparone was high and increased very rapidly (within 24 h) after inoculation, unlike in susceptible species. In a control specimens, that was not inoculated with gray mold fungal spore solution, the concentration of scoparone was very low (12–18 μg-g fresh weight (FW)-1), and its production did not change (Adek and Sztejnberg, 1994). Scoparone and 6,7-dimethoxy-4-methyl coumarin showed stronger inhibitory activities against both B. cinerea and Colletotrichum gloeosporioides than other coumarins (Kuniga and Nesumi, 2011). Scoparone production was induced and stimulated to in a broad range of Citrus species by UV-C irradiation (Kuniga et al., 2005).

UV irradiation induced the production of antifungal phytoalexins, and prevented the development of pathogenic fungal diseases (Langcake and Pryce, 1977; Nigro et al., 1998; Charles et al., 2008). Several studies showed that the UV irradiation induced the production of scoparone and resistance in the flavedo (exocarp) of Citrus fruits (Rodov et al., 1992; D’hallewin et al., 1999). These changes in the concentration and the rate of increase varied among species, organs, and time of harvest (Kuniga et al., 2005). In UV-irradiated Citrus fruits, the decay of Penicillium digitatum was inhibited (Ben-Yehoshua et al., 1992; Kinay et al., 2005). Moreover, in some studies, it was suggested that the application of UV-C might reduce postharvest decay of Citrus (Rodov et al., 1992; Stevens et al., 1996; D’hallewin et al., 1999). Rodov et al. (1992) showed that UV-C (254nm) irradiation induced the production of scoparone in the flavedo of kumquat and orange. The production of scoparone was correlated with the antifungal activity of the flavedo. In addition, UV irradiated kumquat fruits displayed a lower incidence of Penicillium digitatum decay than the control fruits. These results suggested that phytoalexins were induced by UV light and contributed to the observed reduction in disease.

On the basis of these findings, we speculated that the induction of phytoalexins might also inhibit B. cinerea diseases in Citrus. In previous studies, it was reported that UV irradiation reduces the incidence of oranges and mandarins (Kinay et al., 2005; Stevens et al., 1996; D’hallewin et al., 1999). However, few studies have examined the relationship between UV-C irradiation and B. cinerea decay in fruits of other Citrus species. We assumed that UV-C irradiation prevents the development of fungal diseases using a treatment system combining commercial application for transportation and postharvest in tropical and subtropical areas.

In the present study, we investigated the response of Citrus fruits to inoculation with B. cinerea after UV-C irradiation, including scoparone accumulation in flavedo tissue, and resistance to decay in some Citrus species.

Materials and Methods

Materials

The fruits of Satsuma mandarin (Unshu: Citrus unshiu Marc. cv. ‘Silverhill Owari’), ‘Kiyomi’ tangor (C. unshiu × C. sinensis), Hyuganatsu (C. tamurana Hort. ex Tanaka), and ‘Eureka’ lemon (C. limon Burm. forma ‘Eureka’) were collected in mid-January 2007. These species display different characteristics in the two major Citrus taxonomy and nomenclature (Swingle, 1967), and in the production of scoparone (Kuniga et al., 2005; Kuniga and Mastamoto, 2006). The fruits were harvested 8 months after blooming and 2 months after the pigmentation of flavedo to evaluate the characteristics of different Citrus species. Sample fruits from multiple trees were collected from the external part of the canopy and delivered to the laboratory immediately. Fruits were washed with a 70% Et-OH solution and distilled water, subjected to UV-C irradiation, and inoculated with B. cinerea.

UV-C irradiation

The UV-C irradiation procedure followed the method of Kuniga et al. (2005). The treatment was performed in a small (60 × 120 × 70 cm) ventilated irradiation chamber with two UV lamps (GL20; Toshiba, Tokyo, Japan), each with a nominal power output of 20 W. The peak wavelength emitted by each lamp was 254 nm. Fruits were placed individually at a distance of 25 cm from the UV lamps and rotated continuously during the treatment to ensure that the treatment was uniform over the upper fruit surface. The temperature inside the treatment chamber was 20 ± 2 °C. The UV-C irradiation of 290 μW-cm⁻² was carried out for 20 min at the fruit
surface. Irradiated fruits were incubated in the dark at 25 °C and under a 100% relative humidity after the irradiation.

**Gray mold**

*B. cinerea* (No. 2202) was obtained from the Laboratory of Plant Pathology at Kobe University and cultured on a potato dextrose agar medium at a temperature of 25 °C under continuous irradiation from a near-ultraviolet fluorescent lamp (FL30BLB, 3.6 × 106 W·cm⁻²; Toshiba Co., Ltd., Tokyo, Japan). Sporulation occurred within a week. A suspension was prepared by flooding 7-day-old sporulated culture plates with sterilized water and dislodging the conidia using a funnel and cotton. The spore concentration was adjusted to 5 × 10⁶ spores/mL, the concentration that could cause decay, using a hemacytometer. Inoculation was performed according to the method of Rodov et al. (1992) and Atek et al. (1986), with some minor modifications.

**Inoculation with gray mold**

At 4 days after UV-C treatment, fruits were inoculated with *B. cinerea* spores by wounding the UV-C-irradiated flavedo up to a depth of 1 mm (UV-C-irradiated and inoculated fruits: UV-I). Each fruit was inoculated in two areas with the spores, on the opposite sides of the fruit. In the control trials, on the day of harvest or the day after, fruits were inoculated with the spores (non-irradiated and inoculated fruits: N-I). UV-I and N-I fruits were incubated in the dark at 25 °C, under a 100% relative humidity. All the experiments were repeated seven times (replications), using 10 fruits per replication. After these treatments, the disease incidence (*n* = 10) and radius of the decayed areas (*n* = 20) were determined daily for 7 days. The disease incidence were evaluated by observing the rots caused by *B. cinerea*. The choice of inoculation periods and species was based on our previous studies (Kuniga et al., 2005; Kuniga and Matsumoto, 2006).

**Determination of scoparone content**

At 1–7 days post-inoculation (dpi), the flavedo adjacent to the decayed area (1-mm depth and 3-cm radius) was excised using knives, and 5 replicates were collected from each species. The samples were stored at -20 °C. Scoparone content was measured in samples from N-I, UV-I, and fresh flavedo (control fruits that had not been subjected to any treatment on the day of inoculation: 0 dpi) using the method described by Kuniga et al. (2005) with some modifications, according to Kim et al. (1991). The samples were extracted with 80% Et-OH. The extracted solution was centrifuged and evaporated, and the aqueous phase was partitioned with CH₂Cl₂. The CH₂Cl₂ fraction was dried and dissolved with 4 mL of 30% Me-OH. Then, 200 μL of filtered solution was injected for a high performance liquid chromatography (HPLC), and the analysis was carried out using the HPLC system (HPLC LC-2000Plus, JASCO Co., Tokyo, Japan) equipped with a C18 column (Inertsil ODS2 4.6 × 150 mm, GL Science Inc., Tokyo, Japan). The gradient used was 20–70% Me-OH for 26 min, and the flow rate was 1.2 mL min⁻¹ at 40 °C. Scoparone was detected using a fluorescence detector (X-LC 3120FP, JASCO Co., Tokyo, Japan). Fluorescence was monitored with excitation at 330 nm and emission at 400 nm. In addition, the presence of scoparone was confirmed by measuring UV absorbance (335 nm) using a UV detector (UV 2070, JASCO Co., Tokyo, Japan). The retention time of scoparone was approximately 18 min and the concentration was calculated in μg per g FW.

**Statistical analysis**

All the data were subjected to statistical analysis using Student’s and Welch’s t-test, with Statcel 3 (OMS Ltd., Saitama, Japan). These tests were used to calculate the significant differences (*P* < 0.05) between samples, indicating the severity of *B. cinerea* disease.

**Results**

**Disease incidence**

Disease incidence (percentage of flavedo affected by decay due to gray mold) increased rapidly by 3–4 dpi in all the N-I fruits, except for ‘Eureka’ lemon. Satsuma mandarin and Hyuganatsu showed pronounced increases in fungal penetration at 7 dpi (Fig. 1). The disease incidence in the UV-I fruits was lower than that in the N-I fruits in these species at 4 dpi (Fig. 2). In the N-I fruits, the disease incidence exceeded 80% at 4 dpi; while, the disease incidence in the UV-I fruits reached 80% at 6–7 dpi. Both N-I and UV-I ‘Kiyomi’ tangor fruits reached nearly the same state of fermentation at 7 dpi, and no these fruits showed significant differences in disease incidence. The disease incidence in ‘Eureka’ lemon was considerably lower than that in the other species during the same period. In both N-I and UV-I ‘Eureka’ lemons, the disease incidence was below 20%, and there was no significant difference between the treatments.

**Radius of decayed area**

By 5–7 dpi, Satsuma mandarin, ‘Kiyomi’ tangor,
Fig. 1. UV-irradiated (UV-I) and non-irradiated (N-I) fruits of Satsuma mandarin (‘Silverhill Owari’) (A), Hyuganatsu (B), ‘Kiyomi’ tangor (C) and ‘Eureka’ lemon (D) inoculated with gray mold at 7 dpi.

Fig. 2. Rate of decay in UV-irradiated (UV-I) and non-irradiated (N-I) fruits of different Citrus species (Satsuma mandarin, ‘Kiyomi’ tangor, Hyuganatsu and ‘Eureka’ lemon) inoculated with gray mold. Vertical bars represent SE (n = 5). Data sets marked with asterisks are significantly different from N-I as assessed by Student’s and Welch’s t-test: * P < 0.05; *** P < 0.001.
and Hyuganatsu fruits that had been subject to UV-C irradiation showed a decrease of the decayed area. In the UV-I Satsuma mandarin fruits, the average radius of the decayed area was 12.6 mm at 7 dpi, and the decrease was evident by 6–7 dpi (P < 0.01). In contrast, the average decay radius for N-I Satsuma mandarin was 17.0 mm. The decayed areas were larger than those of the N-I fruits for all the other species.

In the ‘Kiyomi’ tangor and Hyuganatsu fruits, the average radius of the decayed area in the UV-I fruits was approximately 1 mm by 1–7 dpi. The penetration of *B. cinerea* in the fruits of these species was smaller than that in the N-I fruits. The average decay radius for N-I fruits of ‘Kiyomi’ tangor and Hyuganatsu extended to 1–2 mm. However, the average radius of the decayed area in ‘Eureka’ lemon fruits did not decrease by UV-C irradiation by 1–7 dpi, whereas the average decay radius for both N-I and UV-I fruits extended to approximately 1 mm (Fig. 3).

**Accumulation of scoparone**

Scoparone accumulation in the inoculated *Citrus* flavedo varied among the species and the treatments. Much higher levels of scoparone accumulated in the UV-I Satsuma mandarin fruits than in the N-I fruits. The flavedo of UV-I fruits accumulated almost 200 μg·g FW⁻¹ scoparone at 4 dpi. In contrast, the N-I fruits accumulated approximately 70 μg·g FW⁻¹ scoparone at most in the flavedo at 3 dpi, and fresh flavedo (0 dpi) accumulated small amounts of scoparone.

Both ‘Kiyomi’ tangor and Hyuganatsu fruits showed a considerable scoparone accumulation following UV-C irradiation and inoculation with gray mold fungi. At 7 dpi, the scoparone content in N-I flavedo was almost 130-fold higher in ‘Kiyomi’ tangor and 200-fold higher in Hyuganatsu than the amount in fresh flavedo (0 dpi). However, the accumulation in the N-I fruits increased gradually during the experiment.

Scoparone accumulated more rapidly and reached higher levels in the UV-I fruits than in the N-I fruits in these two species. Scoparone content in UV-I flavedo was almost 250-fold higher than that in the N-I flavedo in ‘Kiyomi’ tangor and 200-fold higher in Hyuganatsu at 2 dpi. The N-I and UV-I fruits showed significant differences in scoparone accumulation at 1–3 dpi in ‘Kiyomi’ tangor and Hyuganatsu (P < 0.05). However, at 7 dpi, the

![Graphs showing decay radius in UV-irradiated (UV-I) and non-irradiated (N-I) fruits of different *Citrus* species inoculated with gray mold.](image)

**Fig. 3.** Decay radius in UV-irradiated (UV-I) and non-irradiated (N-I) fruits of different *Citrus* species inoculated with gray mold. Vertical bars represent SE (n = 5). Data sets marked with asterisks are significantly different from N-I as assessed by Student's and Welch's t-test: * P < 0.05; ** P < 0.01; *** P < 0.001.
amount of scoparone in these fruits did not significantly differ ($P = 0.43$ in ‘Kiyomi’ tangor and $P = 0.079$ in Hyuganatsu). The rate of decay in ‘Eureka’ lemon fruits was lower than that of the other species.

The average scoparone accumulation in fresh flavedo (0 dpi) was 0 µg g FW$^{-1}$, whereas the amount in the N-I and UV-I fruits was approximately 40 µg g FW$^{-1}$ at 4 dpi in ‘Eureka’ lemon. The amounts were significantly different at 1 dpi and 6 dpi ($P < 0.05$). In the present study, the accumulation of scoparone in citrus flavedo was species-dependent, and it increased with UV-C irradiation and inoculation with fungi (Fig. 4).

**Discussion**

In several reports, it was suggested that phytoalexins reduced the decay caused by gray mold in some crops. For example, Charles *et al.* (2008) reported that there was a significant correlation between the accumulation of rishitin, and disease resistance in UV-irradiated tomato fruits, both before and after inoculation. The amount of rishitin present at the time of inoculation was assumed to be the primary factor in resistance. Accumulation of rishitin after the inoculation appeared to increase the resistance.

In a previous study, it was showed that UV-C treatment affected the development of decay. D’hallewin (1999) found that the phytoalexins, scoparone and scopoletin, accumulated in flavedo tissue, in quantities that depended on the orange cultivar and the age of the fruits after UV-C treatment. Concentrations of phytoalexins rose with the increase of irradiation dose. Neither scoparone nor scopoletin was detected in non-irradiated fruits. Irradiation with UV-C induced a substantial rise in the contents of both scoparone and scopoletin, to levels that inhibited the development of decay.

In our study, we showed that the effect of UV-C irradiation on scoparone accumulation in fruit flavedo was species-dependent. In Satsuma mandarin and Hyuganatsu, we observed a significant correlation between the accumulation of scoparone in the UV-C-irradiated fruits and induced disease resistance after inoculation with gray mold (Fig. 2, Fig. 4). Although at the beginning of the study, fresh flavedos (0 dpi) in all the species contained a small amount of scoparone, the amount

![Graphs showing scoparone accumulation](image_url)

Fig. 4. Scoparone accumulation in UV-irradiated (UV-I) and non-irradiated (N-I) fruits of different *Citrus* species inoculated with gray mold. Vertical bars represent SE ($n = 5$). Data sets marked with asterisks are significantly different from N-I as assessed by Student’s t and Welch’s t-test: * $P < 0.05$; ** $P < 0.01$. 

increased in the UV-I fruits of Satsuma mandarin, ‘Ki-yomi’ tangor and Hyuganatsu. On the other hand, there were few differences in lemon fruits. These differences indicated that scoparone accumulation depended on the Citrus species.

In a previous study, it was observed that UV-C-induced scoparone accumulation differed among the Citrus cultivars, organs, and growth phases. (Kuniga et al., 2005). As well as with UV-C, scoparone was induced by the presence of gray mold in many Citrus species (Kuniga and Matsumoto, 2006). It was observed that the time required to reach the highest scoparone concentration varied among species, periods and treatments, and that the differences in concentration appeared to be related to maturity and to the amounts of substrates, synthetases, and catalases, as well as to other factors.

Presently, we showed that the disease incidence differed among the species that were treated with UV-C irradiation. It is possible that UV-C irradiation can be utilized to induce scoparone accumulation before the fruits are stored, in order to inhibit gray mold decay in several species of Citrus fruits. Scoparone inhibited the growth of Phytophthora gummatis at 97 μg g FW⁻¹ (Afek and Sztejneberg, 1994). This amount was lower than the accumulation in UV-I fruits of Satsuma mandarin at 4dpi in our study.

We showed that scoparone accumulation may be accelerated by UV-C irradiation and that it inhibits gray mold decay in some Citrus species. Satsuma mandarin, ‘Kiyomi’ tangor, and Hyuganatsu accumulated a lower amount of scoparone when they were not subject to UV-C irradiation. UV-C irradiation suppressed the disease incidence in these species, except for ‘Kiyomi’ tangor. The development of the decayed area of the ‘Kiyomi’ tangor fruits was statistically smaller in the UV-I specimens than the N-I specimens at 5dpi (P < 0.01) and 6dpi (P < 0.05).

The scoparone content of the UV-C-irradiated fruits increased considerably in ‘Kiyomi’ tangor and Hyuganatsu, reaching the maximum level of accumulation in the early post-inoculation period. After that, the increase was no longer observed. Finally, the scoparone content in the UV-I flavedo was similar to that of N-I in these species at the end of the experiment. These results suggest that scoparone synthesis and catalysis were activated in the decayed area of gray mold in the UV-C-irradiated fruits, and that the amount of scoparone may be controlled by the balance between phytoalexin synthesis by the host and detoxification by the pathogen in the flavedo. This balance has been observed in the degradation of pisatin by Nectria haematococca in pea plants (VanEtten et al., 1989). The synthesis and detoxification may affect differences in the disease incidence between ‘Kiyomi’ tangor and Hyuganatsu in which the amount of scoparone was similar.

UV-C irradiation induced the synthesis of scoparone and delayed the penetration of B. cinerea in Satsuma mandarin, ‘Kiyomi’ tangor, and Hyuganatsu. It also appeared to decrease decayed areas of these species within 5–7 days after inoculation. However, in ‘Eureka’ lemon, the disease incidence was low and the radius of the decayed area was short; unlike in the other species, a small amount of scoparone accumulated in the flavedo.

In some studies, it was reported that the components of lemon wax aldehydes in the cuticles of the flavedo could readily distinguish from those in clementines, oranges, and ‘Willowleaf mandarins’ (Baker et al., 1975). Moreover, the permeable cuticle in Arabidopsis was associated with a strong resistance to B. cinerea (Besse et al., 2007). In addition, changes in the cuticular lipid composition and cutin polymers enhanced the resistance to B. cinerea. These changes are considered to allow a faster perception of fungal elicitors, easier diffusion of the disease signal to the infection site, faster oxidative burst in the host, and decreased virulence in the pathogen (Mengiste, 2012).

Regarding phytoalexins, Ortúñano (2011) reported that the susceptibility to Penicillium digitatum was cultivar-dependent and suggested that high levels of scoparone, the flavanone hesperidin, and the flavone diosmin may have been the main causes of the differences among C. limon cultivars. The accumulation of scoparone which varied between ‘Villafranca’ and ‘Laphitos’ lemon, and expressed a lower and higher susceptibility to P. digitatum, respectively in their study. These results suggest that some other factors (e.g., physical factors, mold strains, species, or unknown compounds) might inhibit gray mold decay in ‘Eureka’ lemon.

Ballester et al. (2013) found that Penicillium digitatum (Pers.:Fr.) Sacc. elicited a higher diversity of pheno- nolic compounds in ‘Navelate’ orange flavedo than in the albedo (mesocarp). Moreover, only negligible changes were detected in the most abundant citrus flavonoids. However, the coumarin scoparone was one of the compounds with the highest induction rate. They concluded that the scoparone was associated with the defense of citrus fruit against different stresses such as UV light and pathogen infection. These studies indicated that UV irradiation and induction of scoparone are effective in reducing the decay caused by molds.
Our results showed that UV-C irradiation inhibited gray mold disease and induced accumulation of scoparone which could play a reinforcing role in the resistance to B. cinerea in some Citrus species. UV-C radiation could be a useful technique for reducing the incidence of postharvest fungal diseases, particularly since some consumers do not wish to purchase fresh fruits treated with postharvest fungicides in tropical and subtropical areas. For instance, UV-C treatment reduced B. cinerea rot of storage grape (Nigro et al., 1998), and the presence of harmful microorganisms on apricot (Yun et al., 2013). Since UV-C irradiation on apricot was performed in large chambers and conveyor belts (Yan et al., 2014), combination of UV-C irradiation and commercial instruments with packaging systems could be useful for the transport over a long period of voyages from the tropical areas to Japan, and vice versa.

However, the pathway of scoparone synthesis and interspecific diversity of the accumulation in the decayed Citrus fruits should be investigated. Further studies should be conducted on a molecular scale to confirm the effectiveness of new postharvest treatments, such as UV-C irradiation, to control the decay in Citrus fruits.

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